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RE-ORDER NO. 61-474

LUNAR PHYSICAL PARAMETERS STUDY

PARTIAL REPORT NO. 11
AND SUPPLEMENT

BREADBOARD TESTS
OF THE
SURFACE MAGNETIC SUSCEPTIBILITY COILS

WORK PERFORMED UNDER JPL CONTRACT NO. N-33552

SEPTEMBER 20, 1961

TEXACO
INC.

RESEARCH AND TECHNICAL DEPARTMENT

EXPLORATION AND PRODUCTION RESEARCH DIVISION

BELLAIRE, TEXAS

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

1 of 5

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2

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BREADBOARD TESTS

OF THE

SURFACE MAGNETIC SUSCEPTIBILITY COILS

TABLE OF CONTENTS

BREADBOARD TESTS

OF THE

SURFACE MAGNETIC SUSCEPTIBILITY COILS

Introduction

The results of the feasibility study concerning the measurement of magnetic susceptibility on the surface of the moon, as presented in Partial Report No. 7, were, briefly, as follows:

1. Variation of mutual and self inductance of a three coil system placed upon a plane surface could be employed to determine the in-situ magnetic susceptibility of the material lying below the surface.

2. The response of the three coil system to variation in height above the surface allows an "operating point" to be so chosen, for each coil size and geometry, that surface roughness will produce a minimum error in the experimental measures.

3. For an assumed "surface roughness" an optimum coil size, geometry, and operating height can be chosen to minimize errors of measurement.

4. Applying the original surface roughness specification "protuberances of up to 10 cm" required a coil system 50 cm in diameter.

This was too large to be stored within, and manipulated from, the proposed spacecraft. Therefore, it was decided as a compromise to evaluate, for the breadboard model, a coil system 12.5 in. in diameter. Also, it was decided that a very small coil system (2.625 in. diameter) should be examined to see whether or not added convenience of storage and handling could be gained without undue sacrifice in quality of data.

Object

To obtain performance data as described in OUTLINE OF BREADBOARD TEST EXPERIMENTS and to show precision of measurements using a 12.5 in. diameter and a 2-5/8 in. diameter coil arrangement.

Description of Apparatus

Large Surface Coils

The 12.5 in. diameter coils were built as shown in Fig. 1. The epoxy coil spools are 12.5 in., 10.5 in., and 4.5 in. in diameter with 350, 300, and 500 turns, respectively, of No. 28 double formvar copper wire. The 4.5 in. receiver coil is concentric and coplanar with the 12.5 in. transmitter coil. The 10.5 in. diameter transmitter coil is coaxial with and approximately 2 in. above the coplanar arrangement. The coils are connected so that the fields of the two transmitter coils are opposing and thus generate a signal in the receiver coil which is approximately zero in amplitude. Four brass screws connected to the upper transmitter coil allow the mutual inductance between this coil and the receiver coil to be varied. With the bridge (Fig. 2) connected to the coils and the bridge resistances set at approximately the values desired, the four brass screws are adjusted until a null is detected. A change in the value of the bridge setting is then required to correctly phase the bridge to the phase of the signal generated in the receiver coil.

It is possible to set the coil positions so that as the coils are placed over a material having a larger magnetic susceptibility than air, the voltage generated in the receiver coil will change phase 180°. If this occurs, the position of the coil must be changed until all magnetic susceptibilities above air will cause this voltage to increase in amplitude.

To make measurements the coils are first placed in air at least 3 ft. above the material to be measured. The bridge resistances are varied until a null is obtained. The coil assembly is then lowered until it rests on the surface. This will unbalance the bridge. The bridge is then rebalanced. The change in resistance is a function of the magnetic susceptibility of the material.

Small Surface Coils

The 2-5/8 in. surface coils were built as shown in Fig. 3. The coil spools are 2-1/8 in. and 1.5 in. in diameter and wound with 75 and 500 turns of No. 29 copper wire. This type of surface coil requires another coil arrangement located in a position so that no change in the field surrounding it can occur. The two sets of coils are connected so that the transmitter coils induce a current in the receiver coil of one set that opposes the current induced in the receiver coil of the second set. The reference coils are mounted so that the mutual inductance between the transmitter coil and the receiver coil can be changed. This is accomplished by placing the coils on a threaded epoxy rod and holding them in position by epoxy nuts. The correct position of the coils on the reference set is determined by setting the bridge resistors at approximately the values desired. Then the position of the transmitter coil is varied with respect to the receiver coil until a null is obtained. For a complete null a change in the bridge setting is required to match the phase relationship of the bridge to that of the signal from the coils. When the coils are operating in the range of the bridge the locking nuts on the reference coils are set. To make a measurement on an unknown magnetic susceptibility material the bridge is balanced for a condition where both coils are in air (magnetic susceptibility, 1×10^{-6} cgs units), next the surface coil is placed with the flat face against the unknown material, (the reference coil is still in air) and the bridge rebalanced. The change in the resistance is a function of the magnetic susceptibility of the material.

Preparation of Standards

Methods of Obtaining Standards

The calibration of a device to measure in-situ magnetic susceptibility requires a laboratory standard which, in practice, is difficult to realize. The two conditions which this standard must satisfy are:

1. The magnetic susceptibility of the standard must be accurately known.

2. A large homogeneous volume of the standard material is required.

Both 1 and 2 above can be satisfied by a solution of ferric chloride in water. The solution can be homogeneously mixed and by measuring its density, the magnetic susceptibility can be computed. The ferric chloride solution used has a determined magnetic susceptibility of 80×10^{-6} cgs units. The solution was placed in a plywood box 3 ft x 3 ft x 1-1/2 ft., which is sealed with a mixture of beeswax and paraffin. The volume of the standard is not large enough for extremely accurate measurements, but considering the toxic nature of the ferric chloride solution, it is as large as could be safely and conveniently handled with existing facilities. Secondary standards were made by mixing known volumes of sand and iron filings. The magnetic susceptibility per unit volume is proportional to the amount of iron in the mixture, provided that the concentration of iron does not become so large that demagnetization occurs[1]. Dry silica blasting sand with grain sizes varying between 80 and 120 mesh and 40 mesh iron filings are used to prepare secondary standards. Three samples were homogeneously mixed, having a volumetric ratio of 1000 ppm Fe, 10,000 ppm Fe, and 92,000 ppm Fe. The samples were placed in boxes identical to that used to

[1] Dr. Harold Mooney, University of Minnesota, acknowledged by telephone

contain the ferric chloride solution.

Method Used to Determine the Magnetic Susceptibility of Standards

The large surface magnetic susceptibility coils were first placed on the surface of 10,000 ppm Fe mixture. Data were taken to determine the correct distance above the surface for optimum response. Fig. 4 is a plot of change in bridge reading between air and the mixture vs. height of coil above the surface. From this plot, it is seen that the maximum change in (ΔR) occurs when the coils are approximately 1 in. above the surface of the mixture. Since this distance is at the peak of the curve of ΔR vs. height, minimum error will result for measurements made over an irregular surface. Three supports were placed on the lower surface of the coil to maintain a distance of 1 in. from any flat surface. Fig. 5 is a plot showing change in bridge reading (ΔR_3) from air to the mixture vs. the magnetic susceptibility in cgs units of the mixture. This curve was constructed by taking a reading over all four mixtures, the primary standard (ferric chloride) and the three secondary standards. The primary standard (magnetic susceptibility 80×10^{-6}), was plotted on the "ΔR vs. Magnetic Susceptibility" graph. The points representing the iron-sand mixtures cannot yet be plotted on this same graph. In order to plot these points, a separate plot must be made of change between bridge reading in going from air to standard vs. ppm Fe in mixture (Fig. 6). The slope of the curve shown in

Fig. 6 is the same as the slope of a curve representing magnetic susceptibility; therefore, Fig. 6 can be overlayed on Fig. 5 and the X ordinate slipped until the curve of Fig. 6 passes through the 80 x 10^{-6} cgs unit point of Fig. 5. The secondary standards are then located on Fig. 5, a conversion from ppm Fe to magnetic susceptibility has been made.

Method Used to Simulate Surface Irregularities

Figs. 7 and 8 show the irregular surface with the coils shown in one of the positions at which a reading could be made. The irregular surface is made of 1/16 in. plexiglass. The protuberances were made by placing the sheet of plexiglass over a hollow cylinder and heating. When plexiglass was pliable, a blunt tool with 3 in. sphere as point was pushed against the plexiglass and through the hollow cylinder. When the plexiglass became cool the tool was removed leaving a protuberance of the desired height. Three protuberances were made by the above process ranging from 3 in. to 4.5 in. in height. A 1/2 in. hole was drilled in each protuberance so that when plexiglass is lying flat on the surface, the protuberances can be filled with the material of the standard.

Experimental Results

The calibration curve which is used with the large coil for determining the magnetic susceptibility of an unknown material is shown in Fig. 5. In this figure it can be seen that a demagnitization effect occurs as the curve approaches 10,000 x 10^{-6} cgs units. This phenomena was experienced by Mooney[2] and Kalashnikov[3] in the development of similar type calibration curves.

The primary standard and the three secondary standards have been located on the curve. The 1000, 10,000 and 92,000 ppm iron filings in silica sand have a magnetic susceptibility of 290, 2900, and 27,000 x 10^{-6} cgs units. If a calibration curve is needed which will extend to 100,000 x 10^{-6} cgs units another secondary standard should be mixed having approximately 500,000 ppm iron filings in sand, however, the demagnitization effect would become so pronounced that it would be almost impossible to interpret the data.

A plot of change in bridge reading in going from air to the standard vs. the magnetic susceptibility for the small surface coils is shown in Fig. 9. The change in bridge reading per 10^{-6} cgs units is approximately 1/75th of that for the large coils. This decrease in sensitivity is due to the decrease in the mutual inductance of the coil system.

With either coil system it is possible to remove the bridge and measure the resultant voltage on the outputs of the receiver coil. No work was done with this method because of

[2] Mooney, Harold M., Magnetic Susceptibility Measurements in Minnesota, Geophysics, 1952

[3] Kalashnikov, A. G., Determination of the Magnetic Susceptibility of Rocks under Field Conditions, Izvest, Akad, Nauk SSSR, Ser. Geofiz., 1954, No. 5, 415-423

noise generated by local radio stations. This noise is not constant because the coils are not always turned in the same direction and because the interference signals decrease in intensity as the height of the coils above the earth increases. The conductivity of the material being measured causes a phase shift which introduces an error, however, the frequency is low enough that this may not cause errors great enough to be of concern. The feasibility of this method of making measurements should be investigated.

Fig. 10 is a plot of change in bridge readings in going from air to the irregular surface of the standard vs. different placements of the coils over the irregular surface (Fig. 7) for the large diameter coils. Eight readings were taken and plotted with no effort made to make the error a minimum. The true magnetic susceptibility of the standard was 2900×10^{-6} cgs units, the minimum reading obtained was 2300×10^{-6} cgs units which is an error of -21%. The readings that fell above 2900×10^{-6} cgs units were taken with the coil sitting in the position as shown in Fig. 7 (where the protuberances are surrounding the coils and towering above them).

Fig. 11 is a plot of the change in bridge readings from air to the irregular surface of the standard vs. different placements of the small coils over the irregular surface (Fig. 8). Six readings were taken and plotted over the 2900×10^{-6} cgs unit standard. The minimum reading was 800×10^{-6} cgs units which is an error of -72.5%.

If a comparison of the two sets of coils is to be made on the basis of making measurements over an irregular surface the large coils are better in that over the same irregular surface an error of 21% exists as compared to 72.5%. This large error for the small coils exist for several reasons: 1) the peak response occurs when the coils are flat on the surface. Fig. 12 is a plot of change in bridge reading from reading on the surface vs. reading at given heights above the surface for the small diameter coils. It can be seen that at a 3/16 in. height above the surface an error of 50% exists. 2) The coils average the volumetric magnetic susceptibility of the material under the influence of their fields, therefore, when the small coils change from their flat most accurate measuring position to a position in which one side is in air a few tenths of an inch, large errors exist. This is not as pronounced an error for the large coils because the volumetric magnetic susceptibility has changed very little. Fig. 13 is a plot of change in bridge reading from reading with no fissures vs. reading with designated fissures for the small diameter coils. This plot shows that a flat surface with fissures 3/16 in. wide will produce errors of 50%. Part of this error can be attributed to the inhomogeniety of the material caused by the insertion of the 1/16 in. plexiglass plates.

Tests were run to determine how near the coils could be operated with respect to large masses of metal. The large coils should be at least 4 ft. from large sheets of aluminum or iron, the small coils could be operated within 8 in. of these plates. A test was run to determine the effect of a 1/2 in. aluminum tube on the large diameter coils - this aluminum tube could be used to lower the coil after a reading was taken in air. This tube should not be in a position closer than 24 in. to the coils when a reading in air is taken. The small coils can be operated with the tube 8 in. above them. The sheets of metal or the tube cause an effect which is not characteristic of the calibration samples in that the bridge reading increases from the reading in air as the metal becomes closer. This phenomena can be attributed to a distortion in the field surrounding the coils and to a large increase in the conductivity of the media.

Conclusion

The breadboard devices built by Texaco to measure the in-situ magnetic susceptibility have a linear range to approximately $10{,}000 \times 10^{-6}$ cgs units, and a calibration curve can be made which would enable measurements approaching $100{,}000 \times 10^{-6}$ cgs units.

The large 12.5 in. diameter coils are the least susceptible to error, the maximum error that was found over a standard irregular surface was -21% compared to -72% for the small coils.

With proper construction the large coils could be built so that they would weigh less than 3 lbs.

The large coils can be no closer than 4 ft. to large metal objects or closer than 24 in. from a 1/2 in. diameter aluminum tube which could be used to hold the coil for the measurement in a vacuum before lowering it to a surface. The small coils should be no closer than 8 in. to a large metal object or any type metal structure used to manipulate it.

Temperature changes cause more error in the large coil than in the small coils; however, with proper materials and structure part of this error could be eliminated.

Summary

1. A calibration curve using both small and large coils can be made with a range from 1 to 100,000 x 10^{-6} cgs units.

2. The maximum error over the standard irregular surface is -21% for large coils and -72% for small coils.

3. The large coils could be constructed to conform with the 3 lb. weight limit.

4. The large coils can be no closer than 4 ft. to large metal objects and no closer than 2 ft. to a metal supporting beam.

5. The small coils can be no closer than 8 in. to metal objects consisting of spacecraft or manipulating hardware.

6. Temperature changes cause more error in large coils than small coil measurements.

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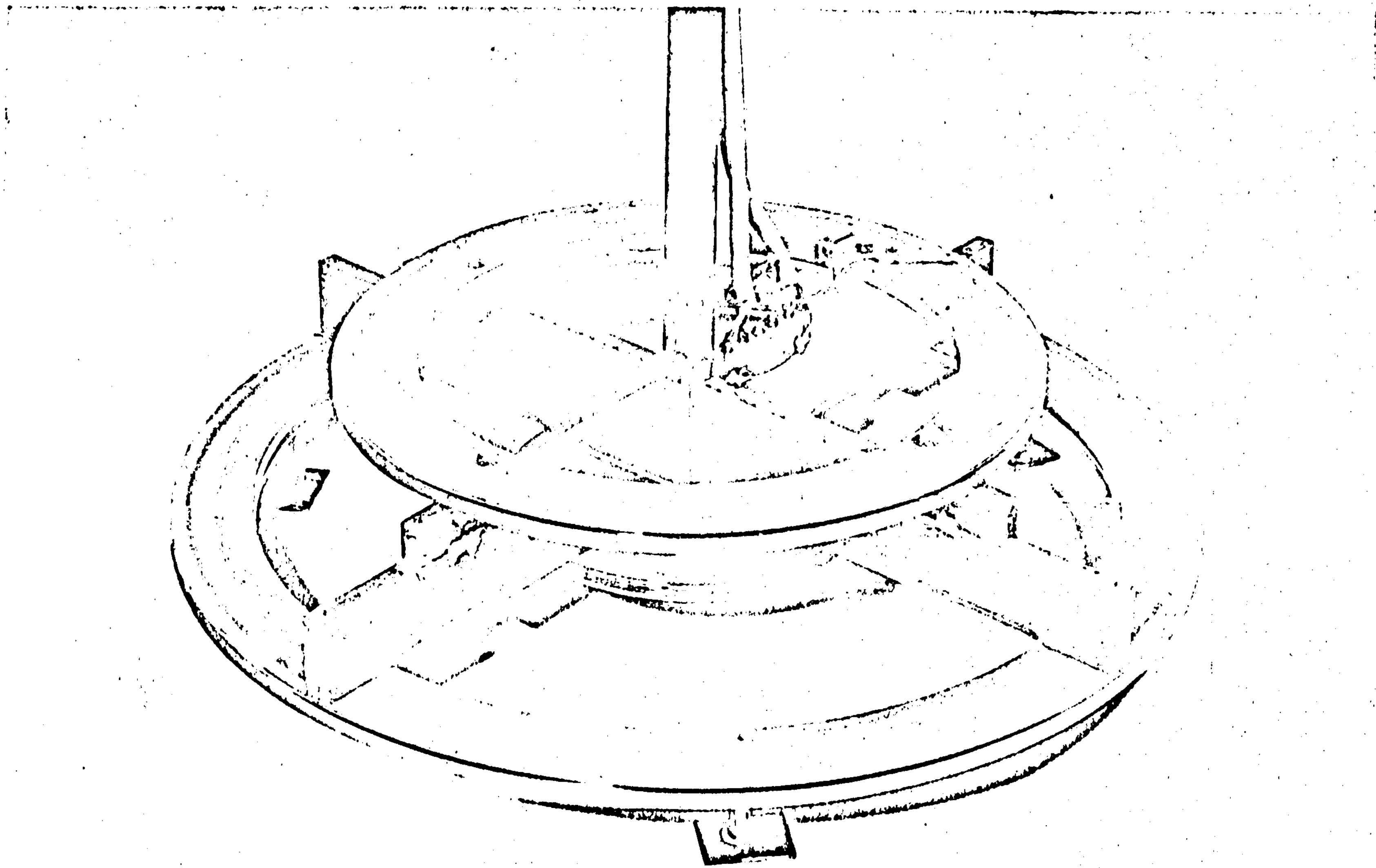


FIGURE 1

LARGE SURFACE MAGNETIC SUSCEPTIBILITY MEASURING COILS

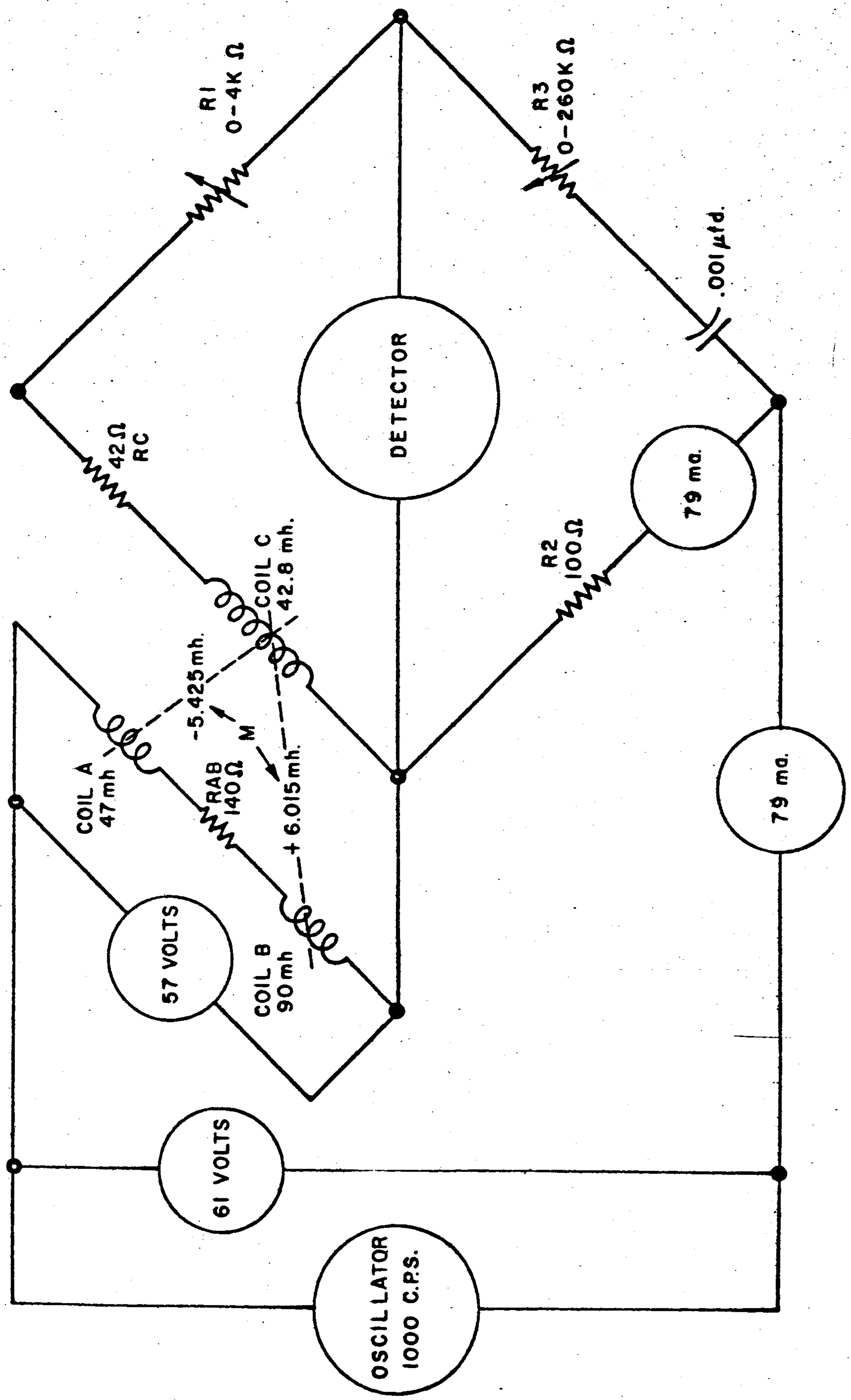
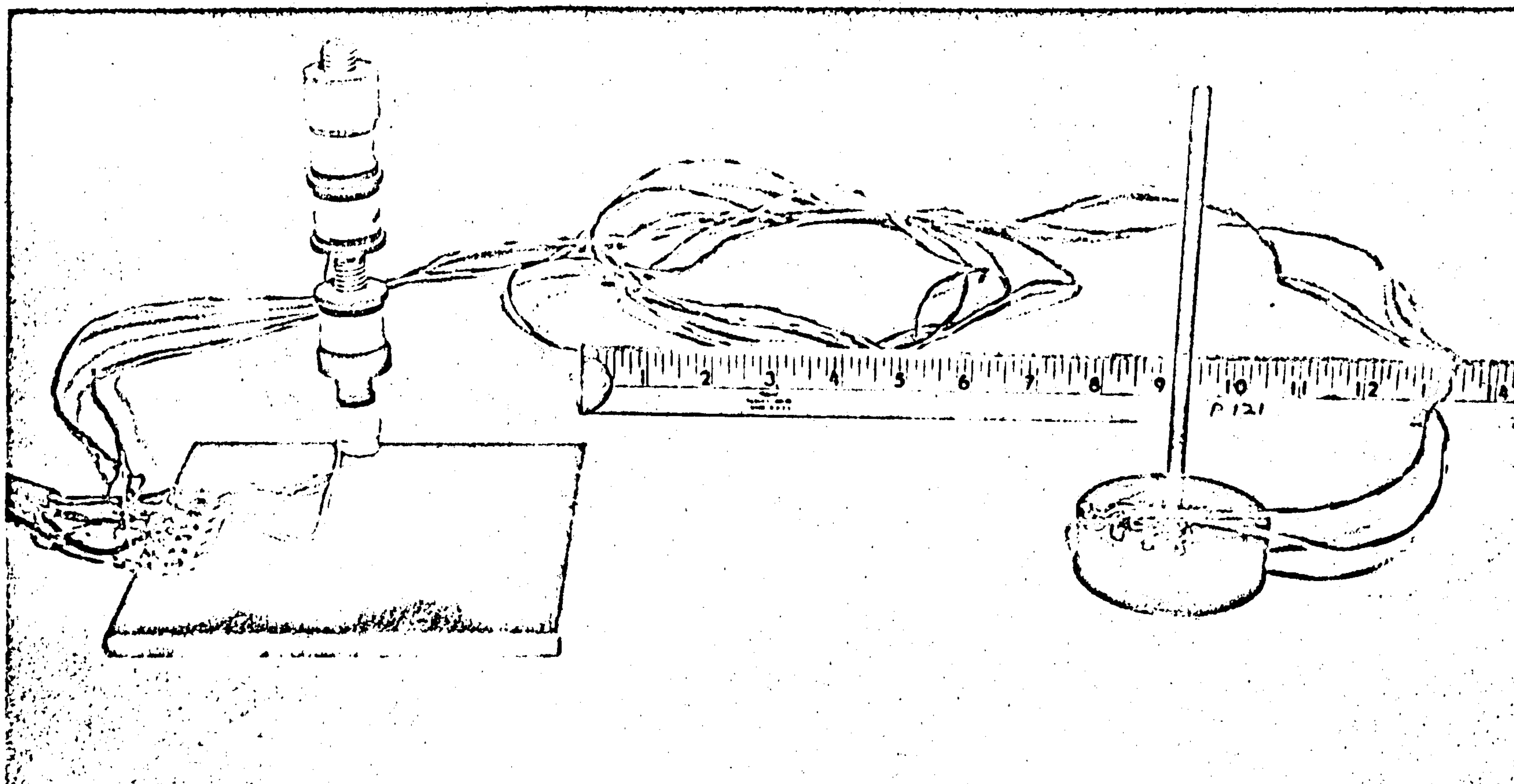

R1
0-4K Ω
R3
0-260K Ω
.001 µfd.
DETECTOR
42Ω
RC
79 ma.
COIL C
42.8 mh.
R2
100Ω
-5.425 mh.
M
+6.015 mh.
COIL A
47 mh
RAB
140Ω
79 ma.
57 VOLTS
COIL B
90 mh
61 VOLTS
OSCILLATOR
1000 C.P.S.

FIGURE 2



NULL COIL ASSEMBLY
USED WITH SMALL COILS

SMALL MAGNETIC
SUSCEPTIBILITY MEASURING COILS

FIGURE 3

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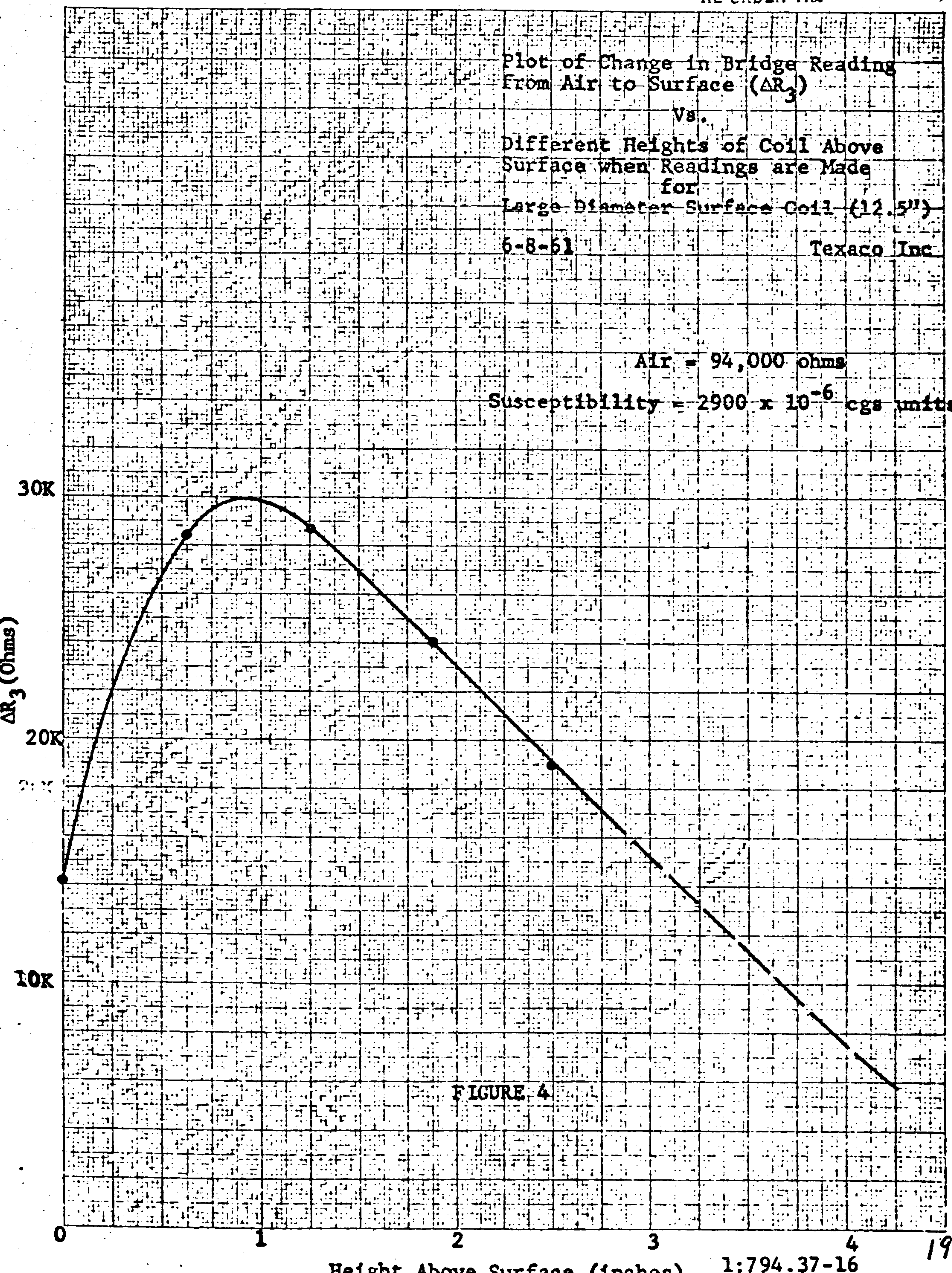

FIGURE 4

1:794.37-16
1:794-101

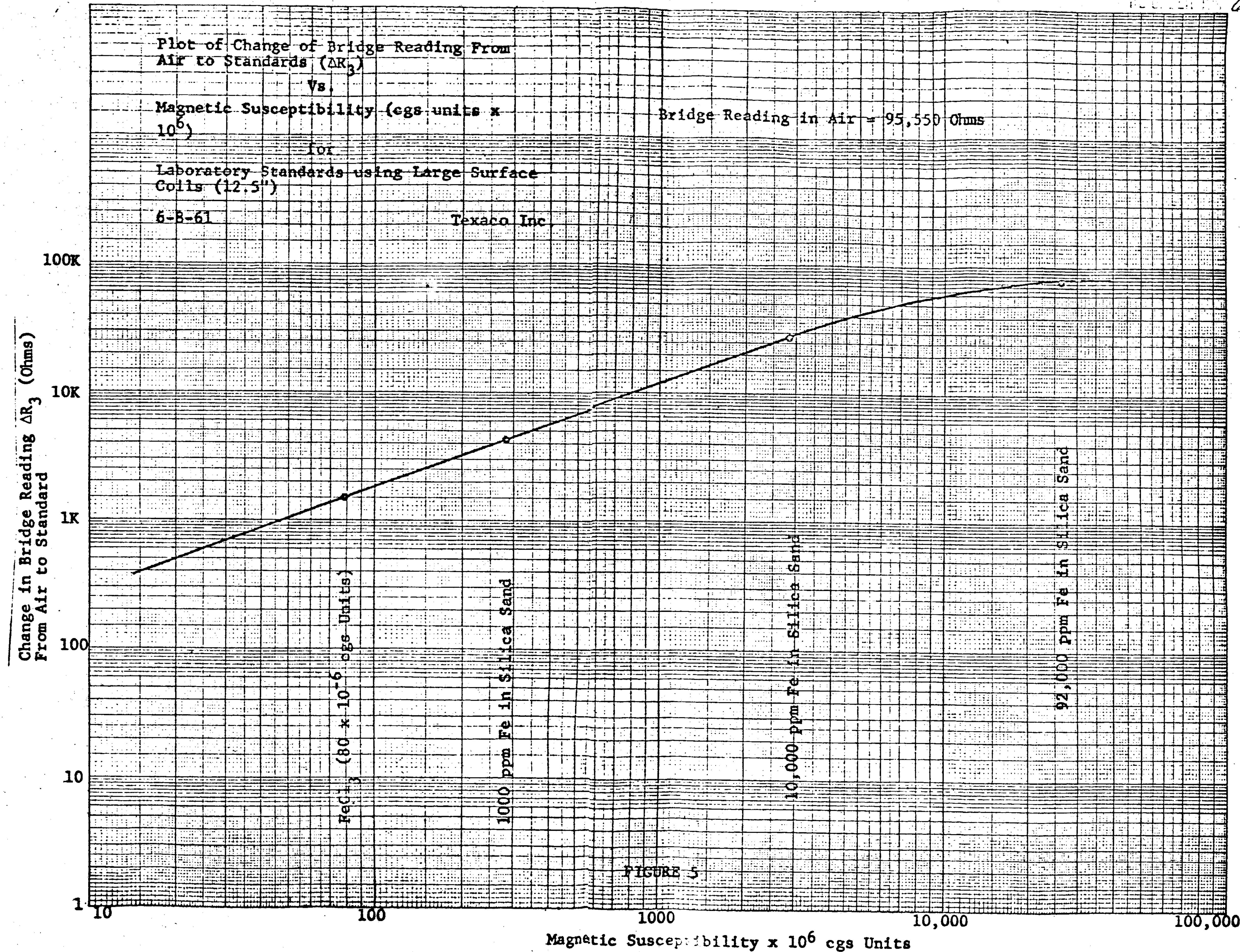

FIGURE 5

1:794.37-17
1:794-102

61-474

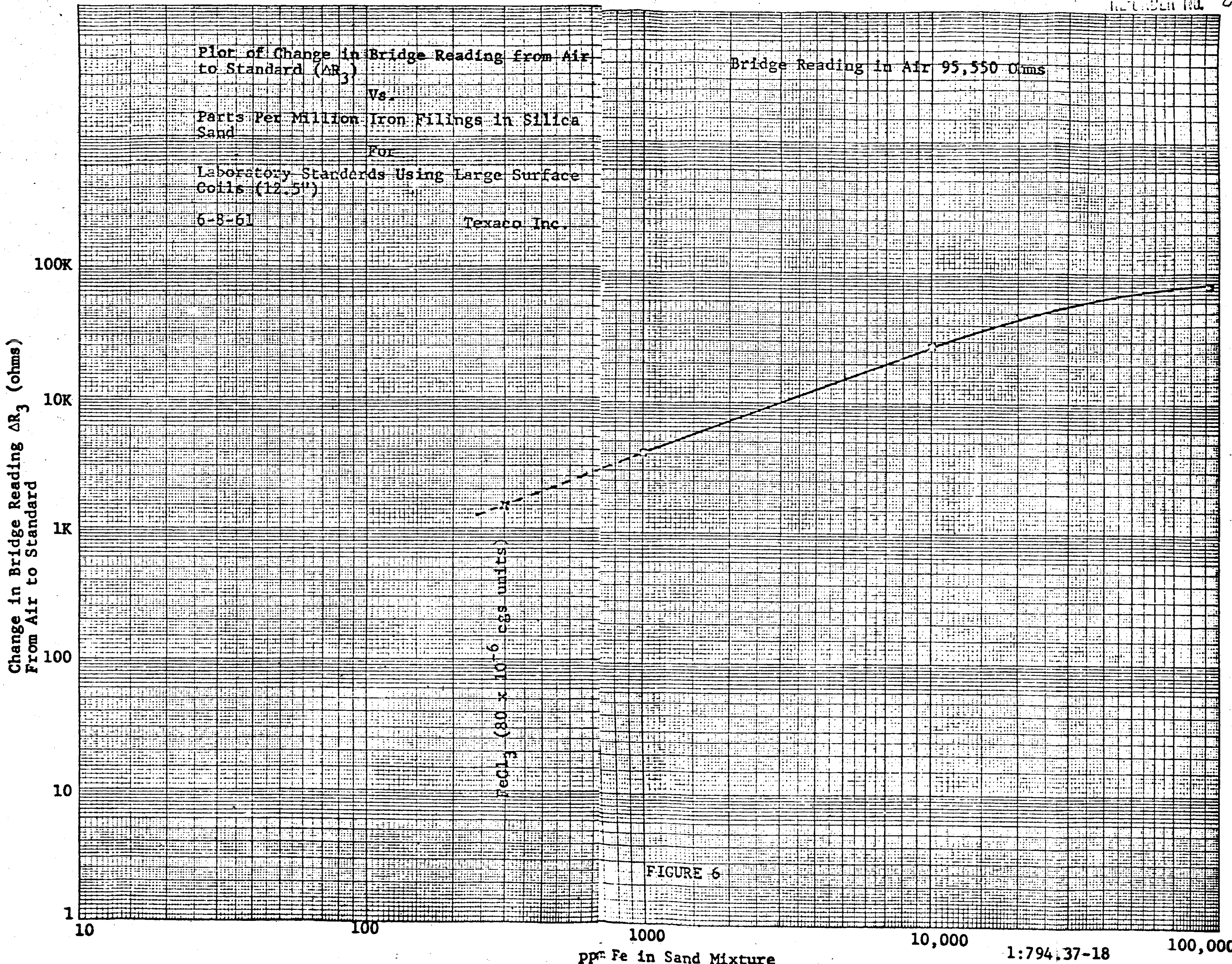

FIGURE 6

1:794.37-18
1:794-103

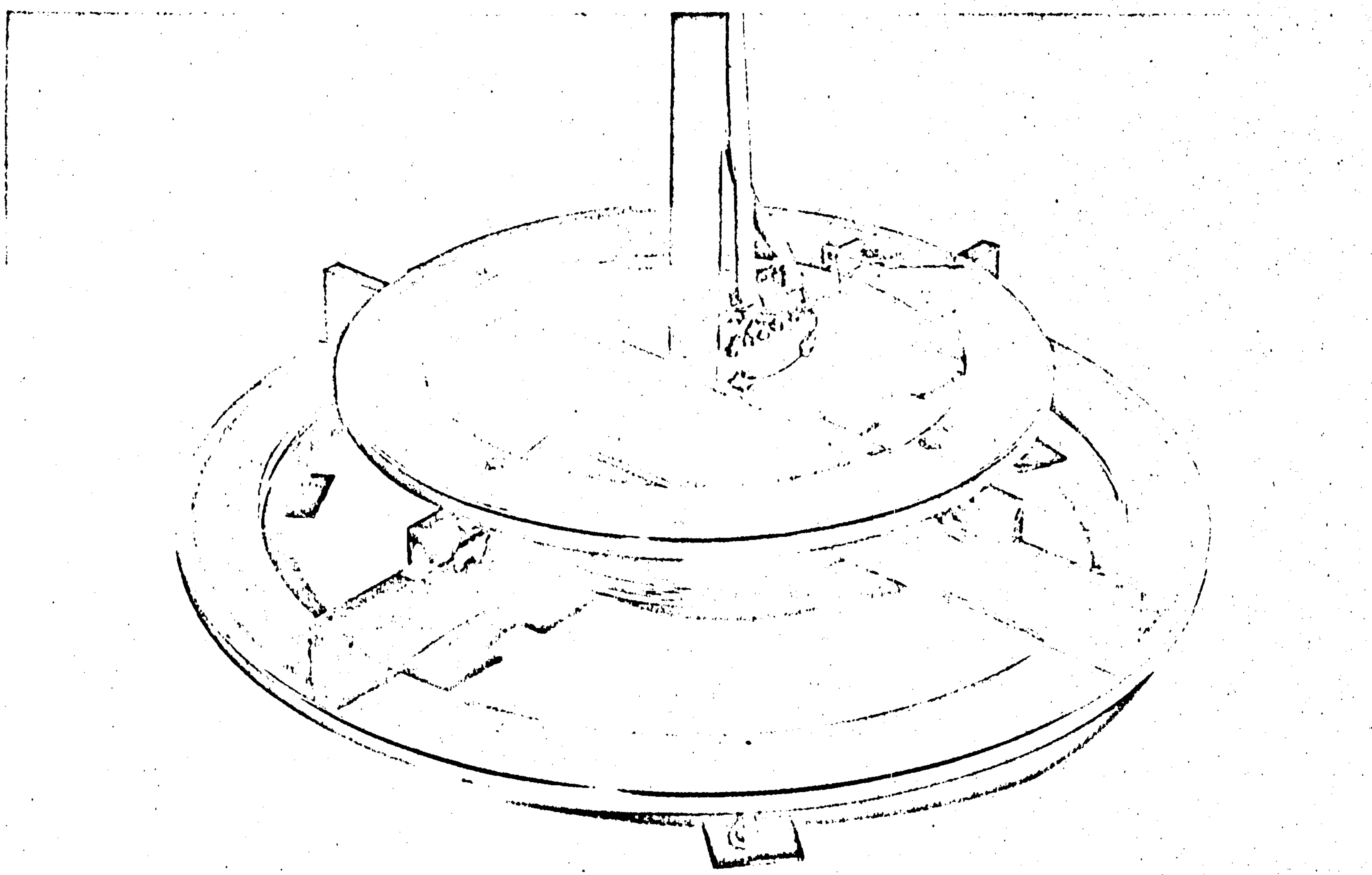

FIGURE 1

LARGE SURFACE MAGNETIC SUSCEPTIBILITY MEASURING COILS

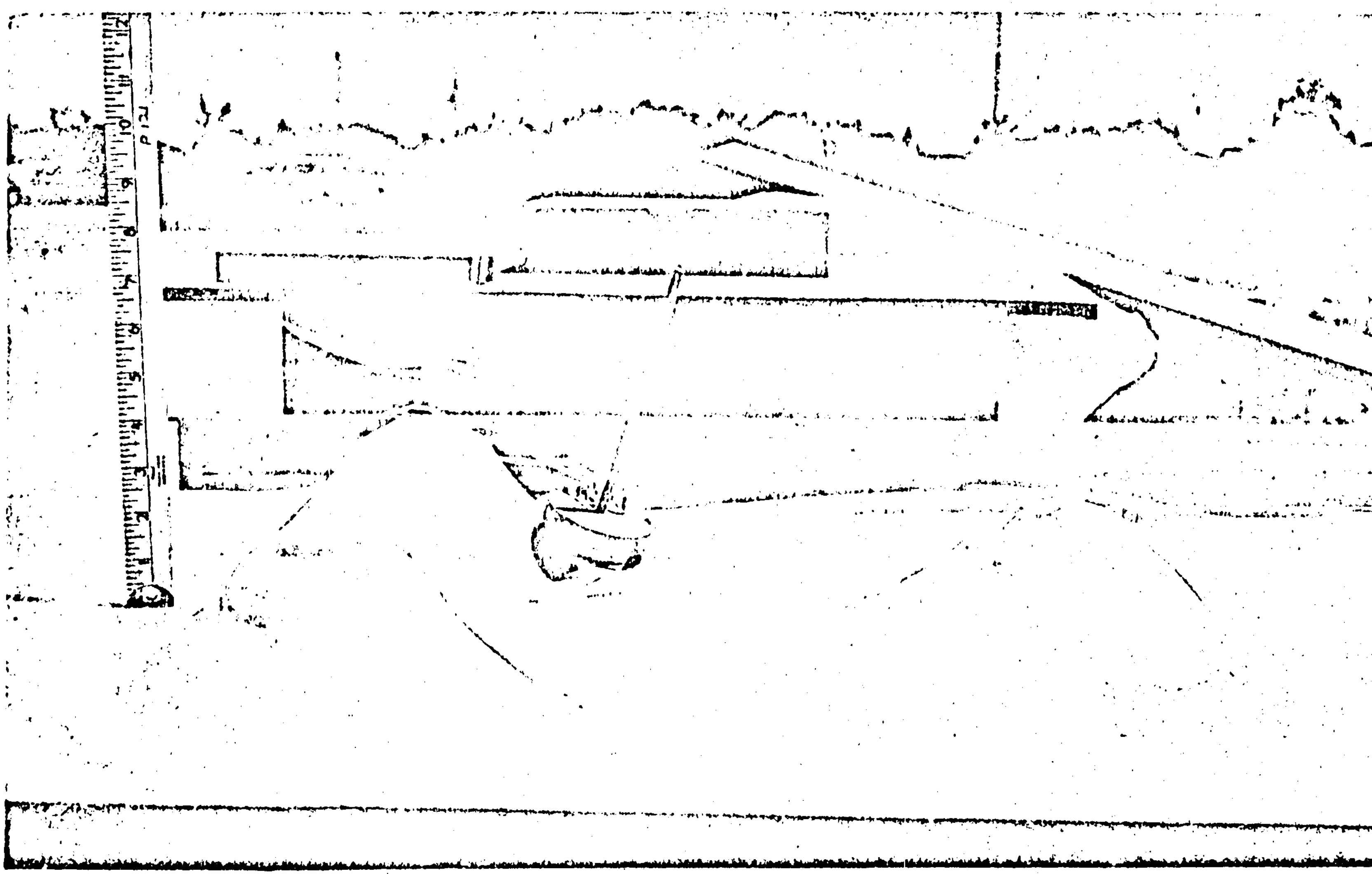

FIGURE 8

SIDE VIEW OF SIMULATED IRREGULAR SURFACE WITH
SMALL MAGNETIC SUSCEPTIBILITY MEASURING COILS

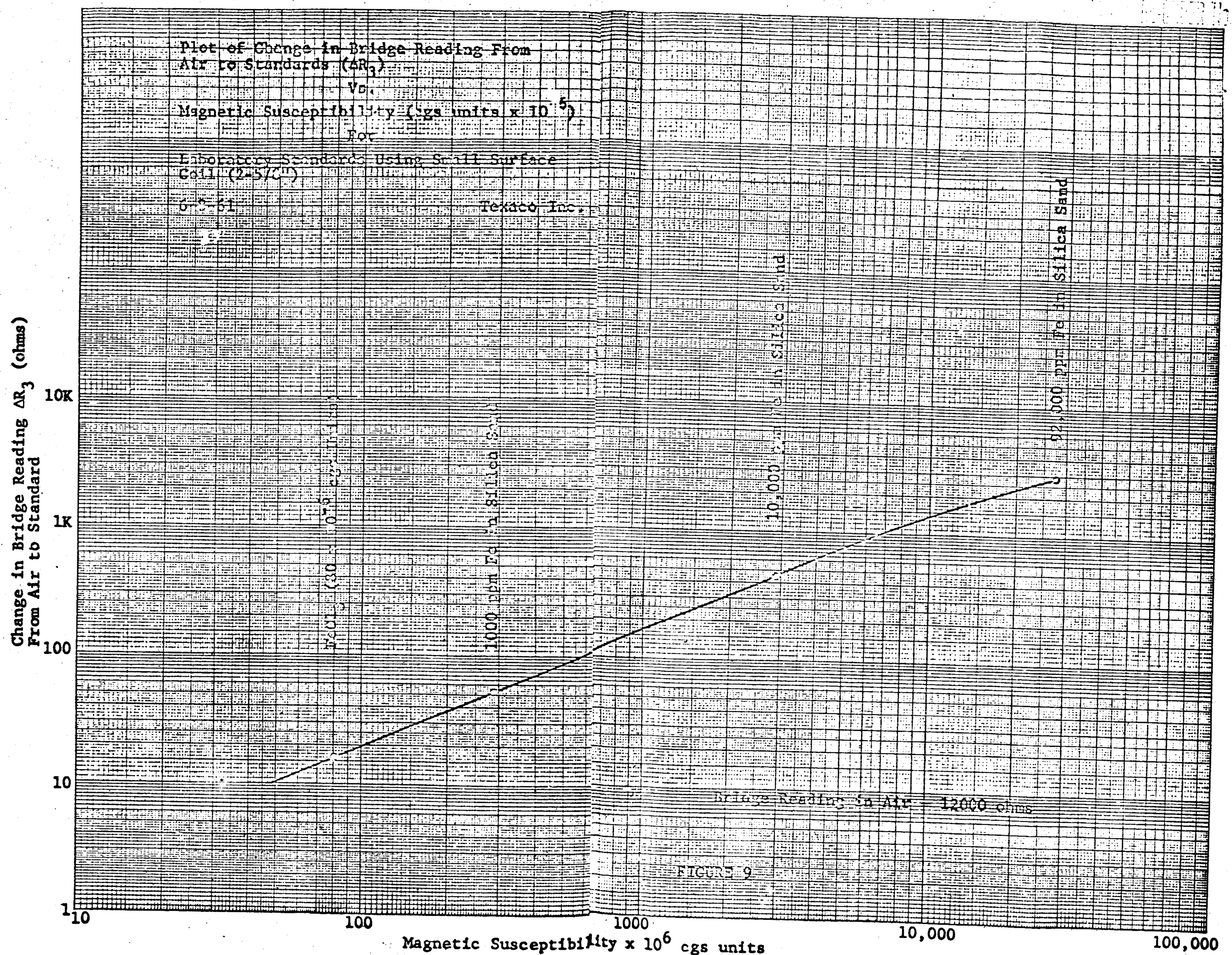

FIGURE 9

1:794.37-21
1:794-104

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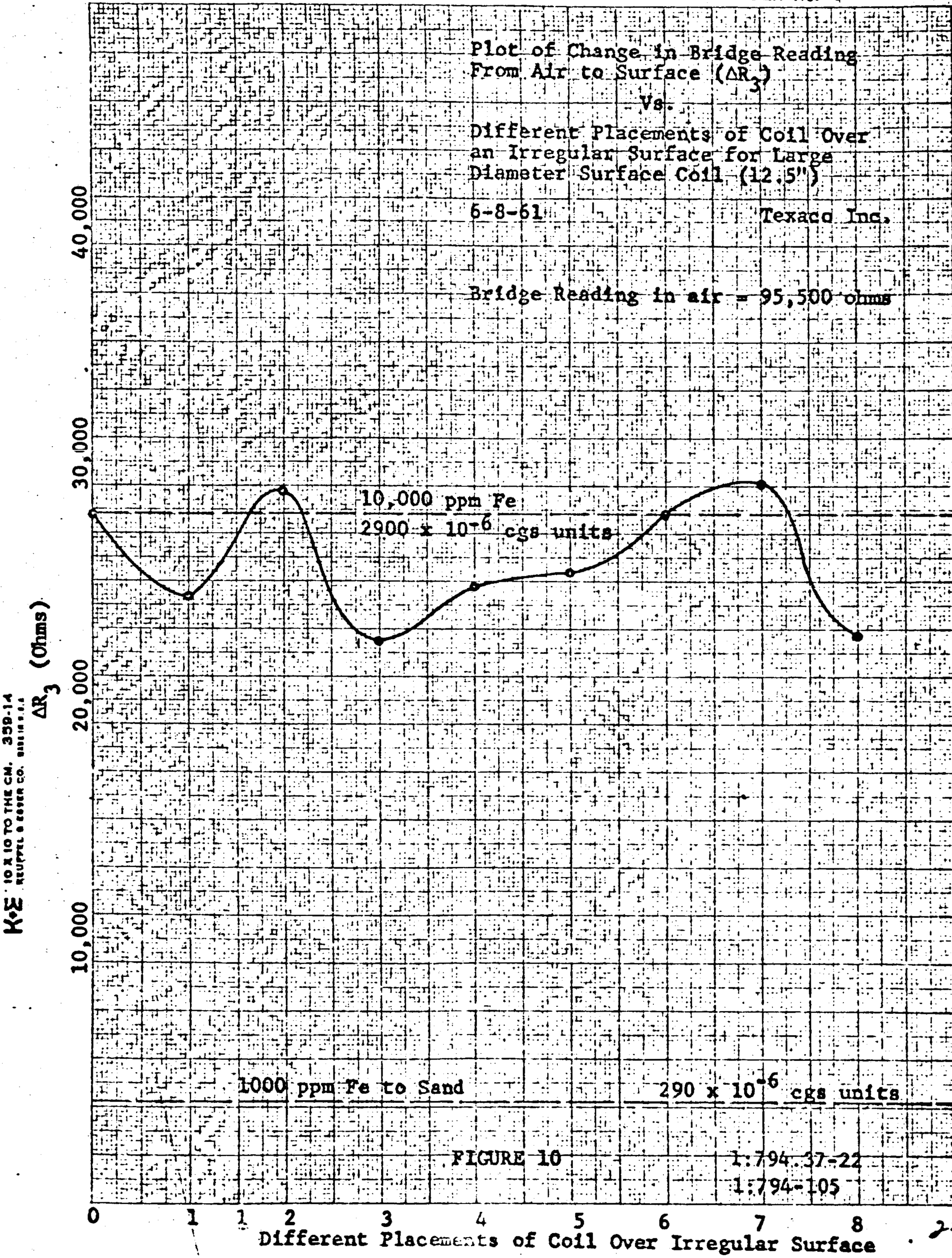

FIGURE 10

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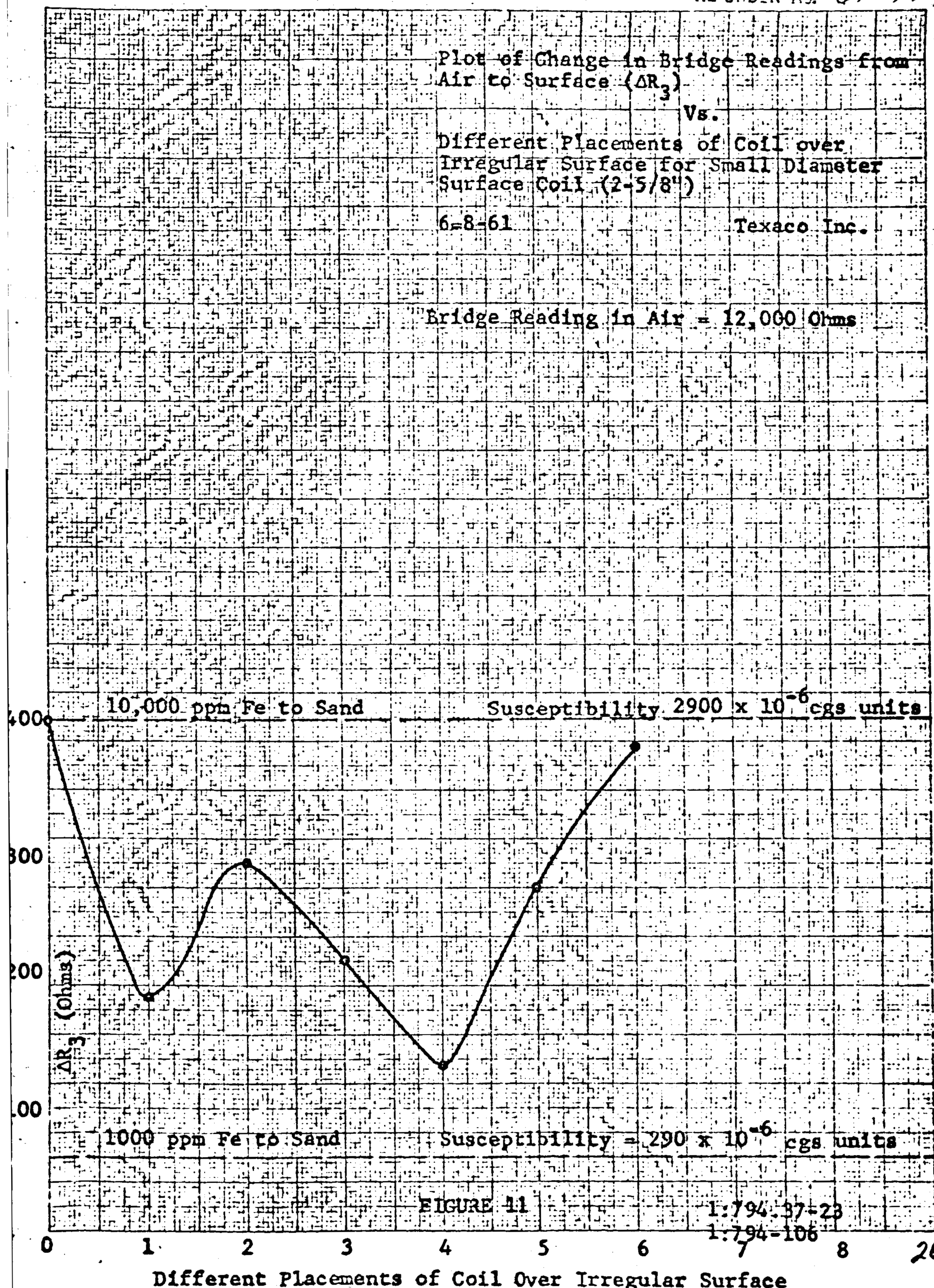

FIGURE 11

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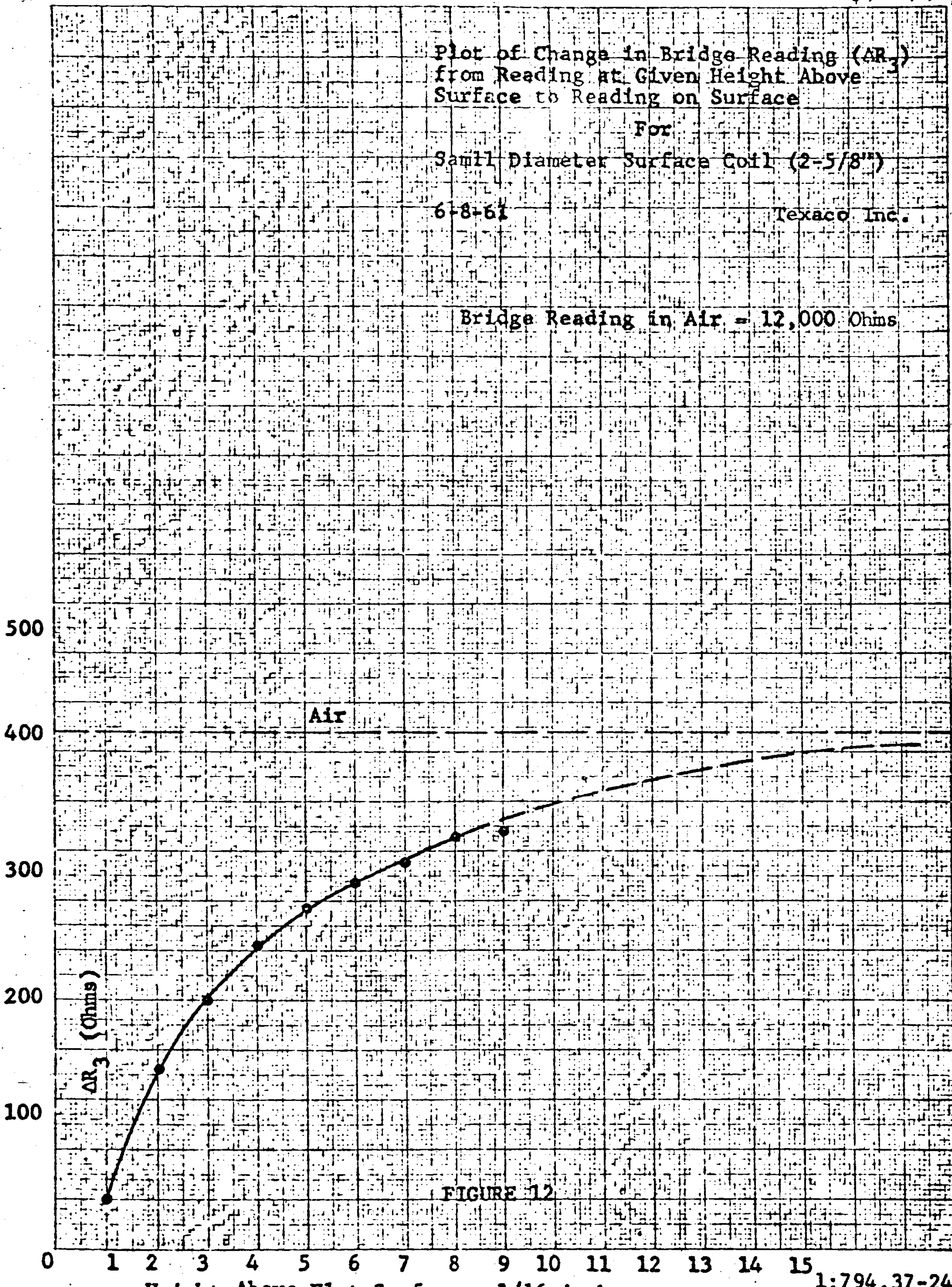

1:794.37-24
1:794-107

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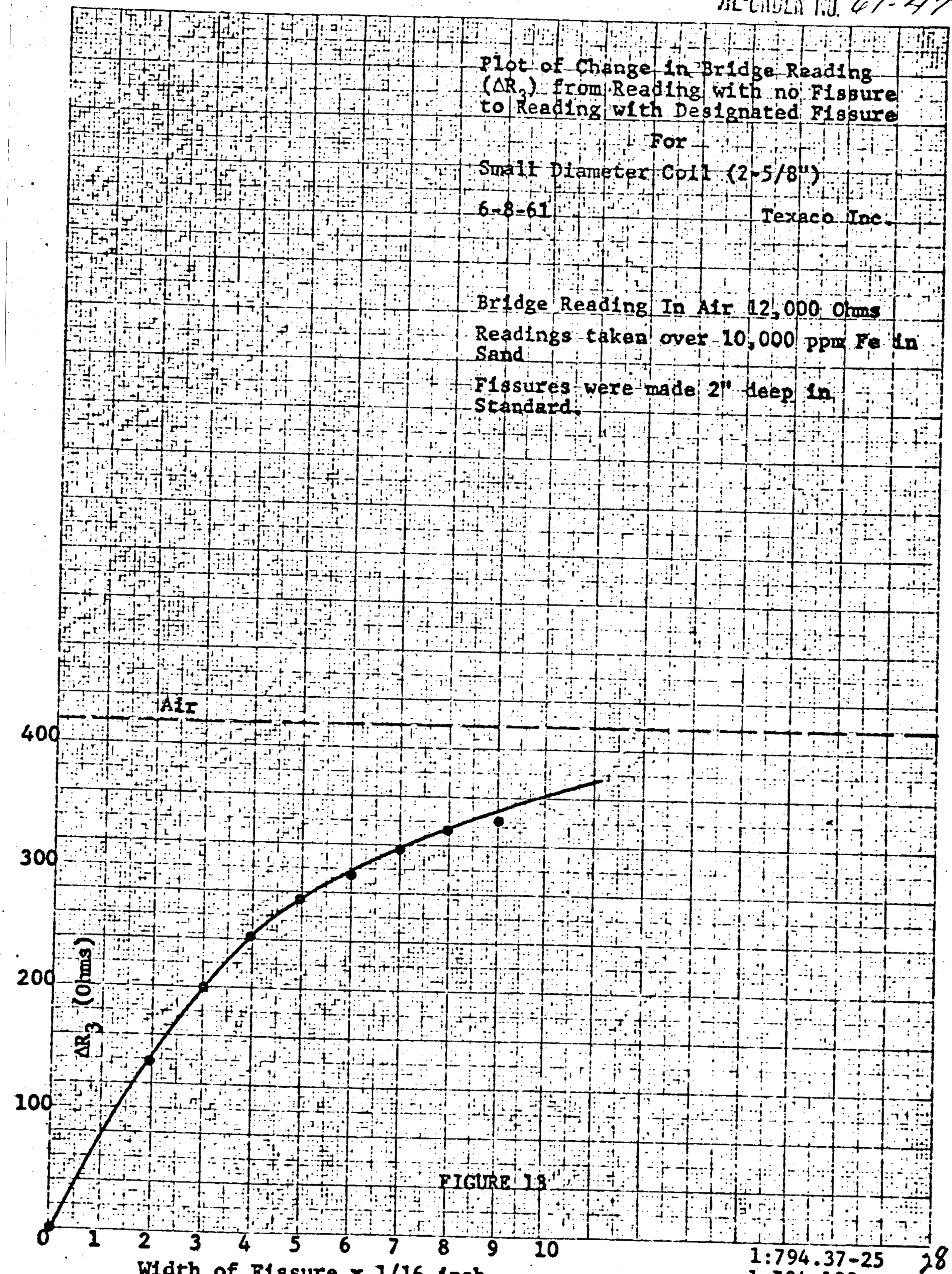

FIGURE 13

1:794.37-25
1:794-108

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LUNAR PHYSICAL PARAMETERS STUDY

A SUPPLEMENTARY REPORT

TO

PARTIAL REPORT NO. 11

BREADBOARD TESTS OF THE 4½ INCH SURFACE MAGNETIC SUSCEPTIBILITY COILS

WORK PERFORMED UNDER JPL CONTRACT NO. N-33552

SEPTEMBER 20, 1961

29

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BREADBOARD TESTS OF THE 4-1/2 INCH SURFACE MAGNETIC SUSCEPTIBILITY COILS

A SUPPLEMENTARY REPORT TO PARTIAL REPORT NO. 11

The 4-1/2 in. diameter coils shown in Fig. A1 were built as an intermediate between the 12-1/2 in. and the 2-5/8 in. coils. The 12-1/2 in. coils can be used to obtain reliable data over the prescribed irregular surface, but their weight and size is objectionable. The 2-5/8 in. coils are small and could be built to weigh only a few ounces, but the quality of data recovered is poor. Hence, it was thought that with an intermediate size coil reliable data could be obtained with less weight and volume of material.

This coil system uses the three coil inductive balance system with Coil A located approximately 1 in. axially above a coplanar arrangement of Coils B and C. Coils A, B and C have, respectively, 275, 450 and 500 turns of No. 29 copper wire. The procedure for setting the coil positions is similar to that for the 12-1/2 in. diameter coils described in Partial Report No. 11. The results of the tests of these intermediate coils are shown in Figs. A2, A3, and A4.

Fig. A2 is a plot of the change in bridge reading vs. magnetic susceptibility. It can be seen from this plot that the slope of the curve is approximately the same as the slope

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for the 12-1/2 in. coil shown in Fig. 5 of Partial Report No. 11. Demagnitization effects are approximately the same, and both curves tend to flatten above 10,000 x 10^{-6} cgs units.

Fig. A3 is a plot of change in bridge reading vs. different placements of the coils over the standard irregular surface. The true magnetic susceptibility of the standard was 2900 x 10^{-6} cgs units. The reading which shows the maximum error is 1700 x 10^{-6} cgs units. This is an error of -42%.

Fig. A4 is a plot of change in bridge reading in going from air to standard vs. height above the surface of standard. It can be seen that the maximum sensitivity occurs when the coils are approximately 1/4 in. above the surface. Accordingly, 1/4 in. legs were made and placed on the bottom of the coils.

Tests show that the coils should be operated no closer than 24 in. to large metal objects or 18 in. to metal support members.

Summary

The 4-1/2 in. coil system which was built to minimize weight and volume problems has a calibration curve with the same linear range and slope as the 12-1/2 in. coils.

The maximum error of measurement over the standard irregular surface was -42% compared to -21% for the 12-1/2 in. coils and -72% for the 2-5/8 in. coils.

The 4-1/2 in. coils can be no closer than 24 in. to large metal objects or 18 in. to metal support members.

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4-1/2" Medium Size Magnetic
Susceptibility Coil Forms

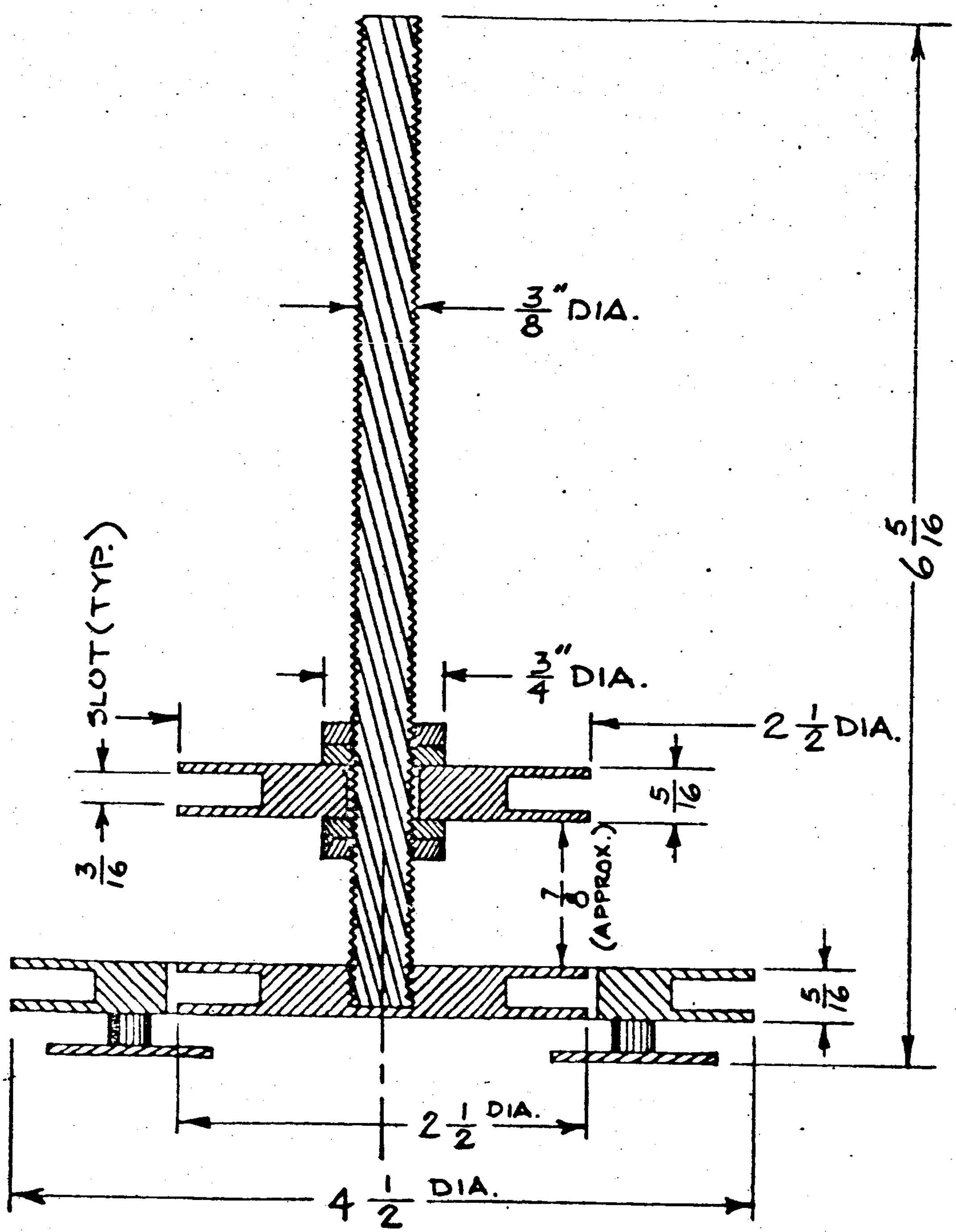
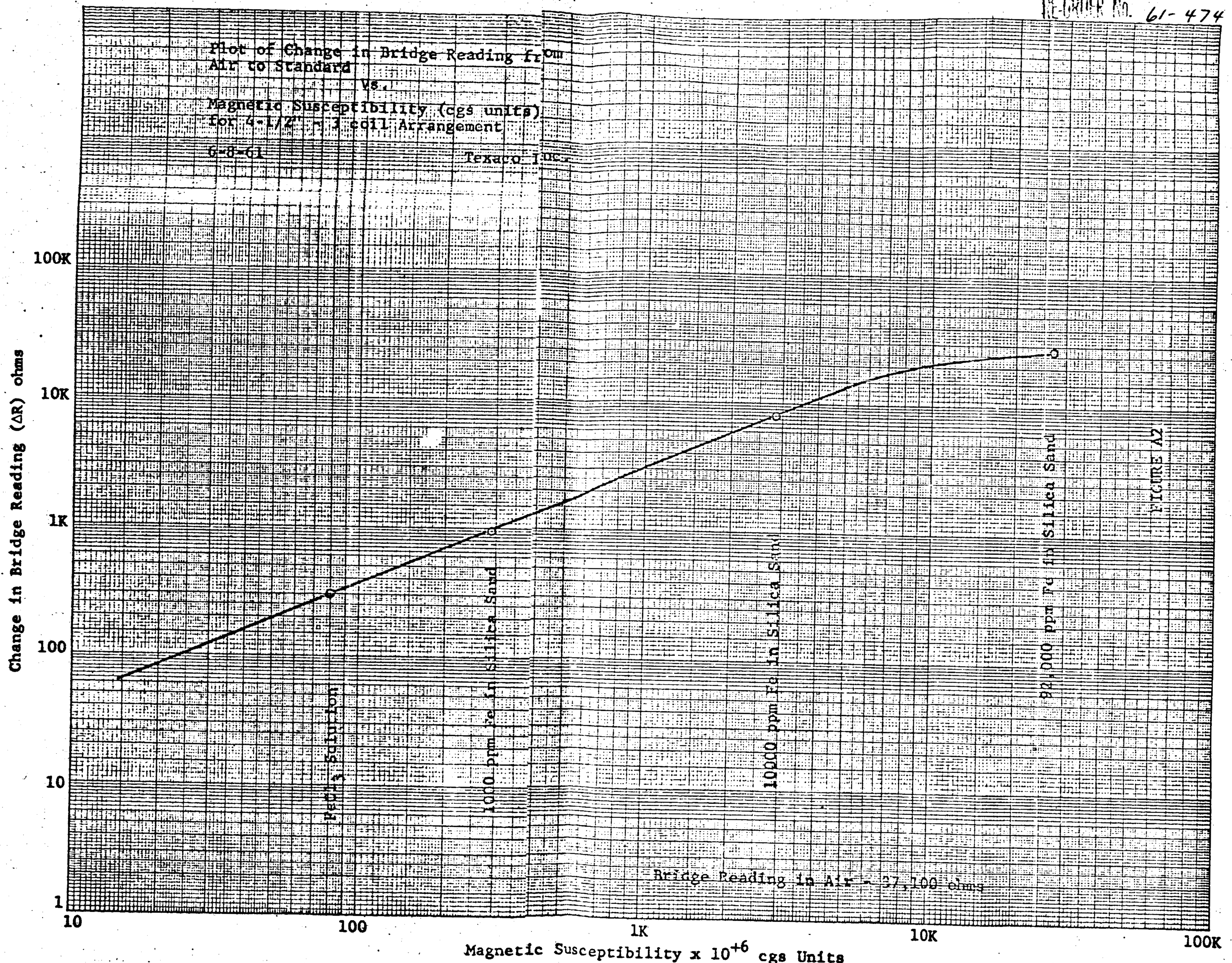


FIGURE A1

32

1:794.40-3
1:794-82



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1:794-83

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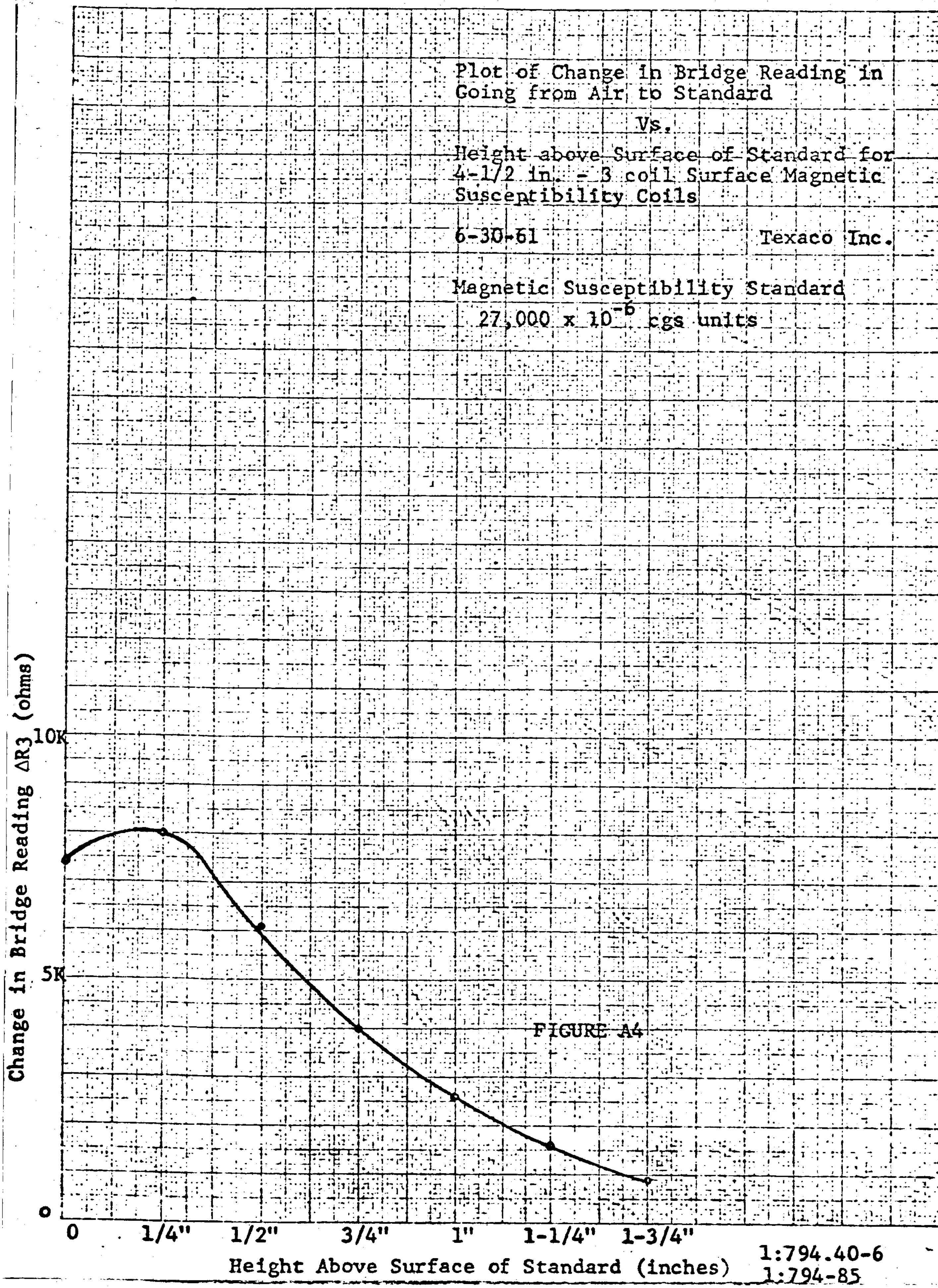

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